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(54) OVERLAY TUNNEL IN A FABRIC SWITCH

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See application file for complete search history.

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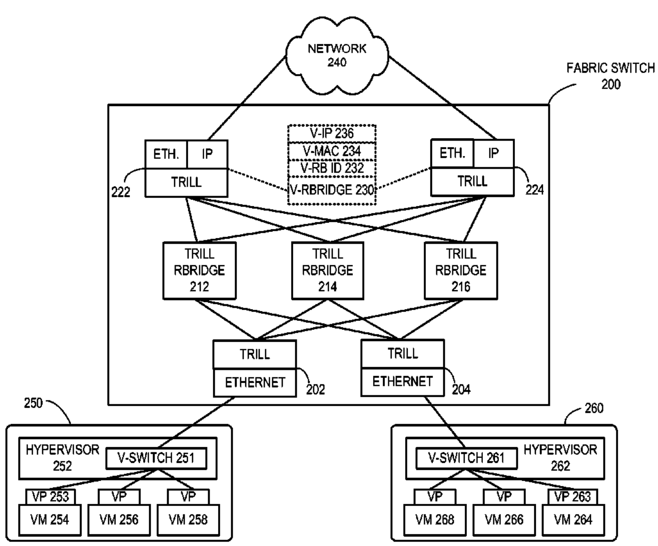
(57) **ABSTRACT**

One embodiment of the present invention provides a switch. The switch includes a tunnel management module, a packet processor, and a forwarding module. The tunnel management module operates the switch as a tunnel gateway capable of terminating an overlay tunnel. During operation, the packet processor, which is coupled to the tunnel management module, identifies in a data packet a virtual Internet Protocol (IP) address associated with a virtual tunnel gateway. This virtual tunnel gateway is associated with the switch and the data packet is associated with the overlay tunnel. The forwarding module determines an output port for an inner packet in the data packet based on a destination address of the inner packet.

22 Claims, 11 Drawing Sheets



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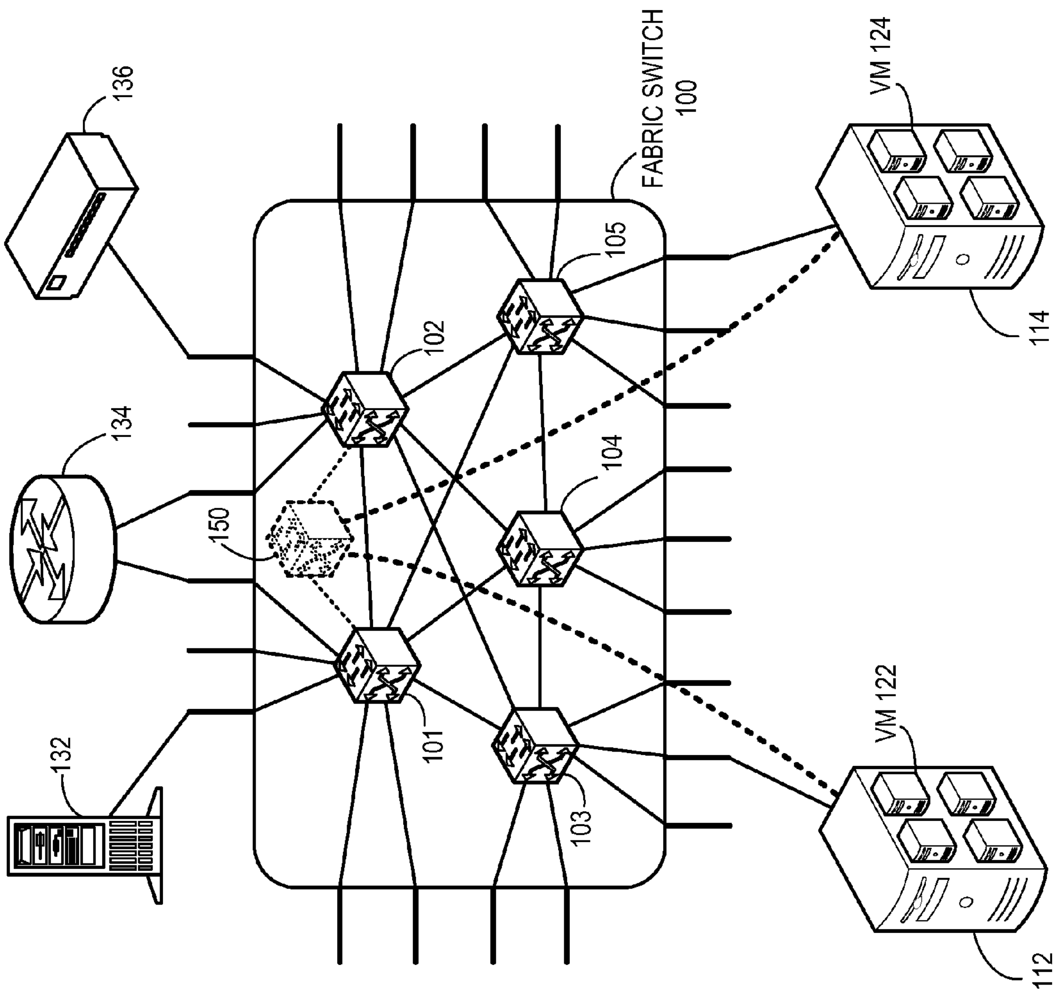
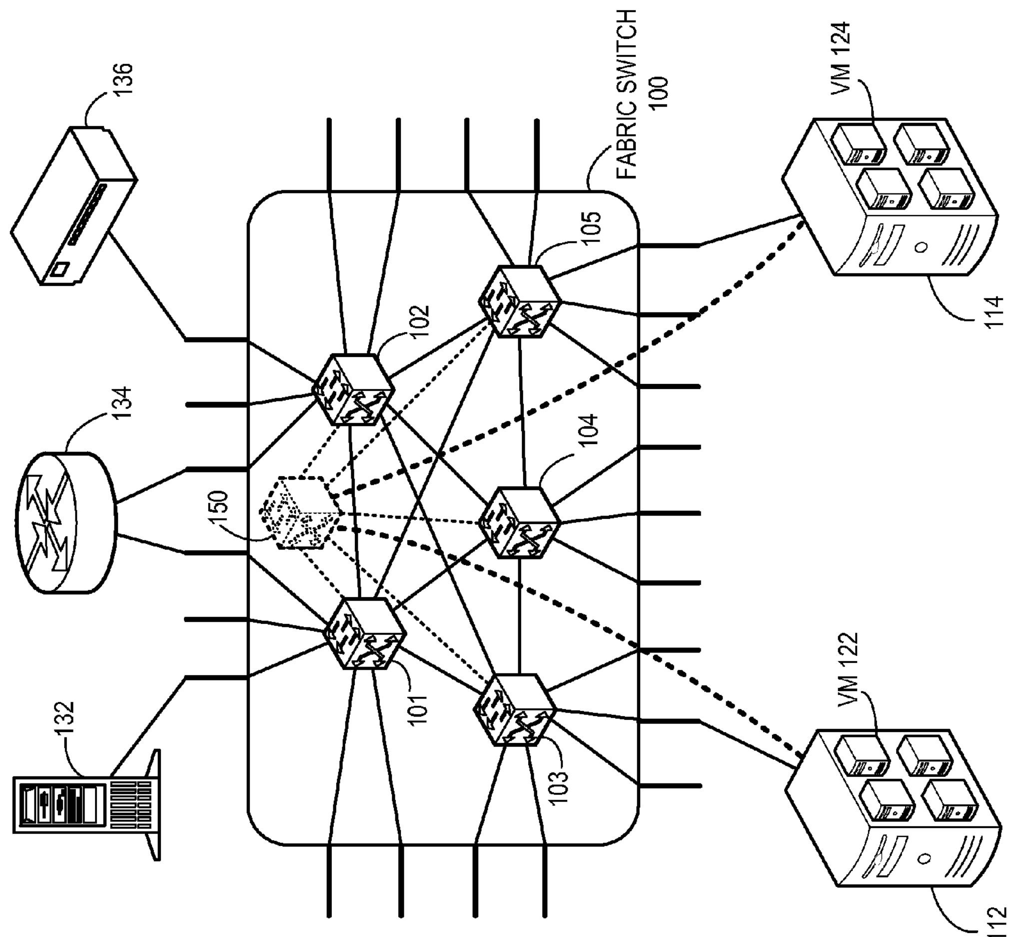

136
134
132
150
102
105
104
101
103
FABRIC SWITCH
100
VM 124
114
VM 122
112

FIG. 1A


136
134
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FABRIC SWITCH
100
102
105
104
150
101
103
VM 124
114
VM 122
112

FIG. 1B

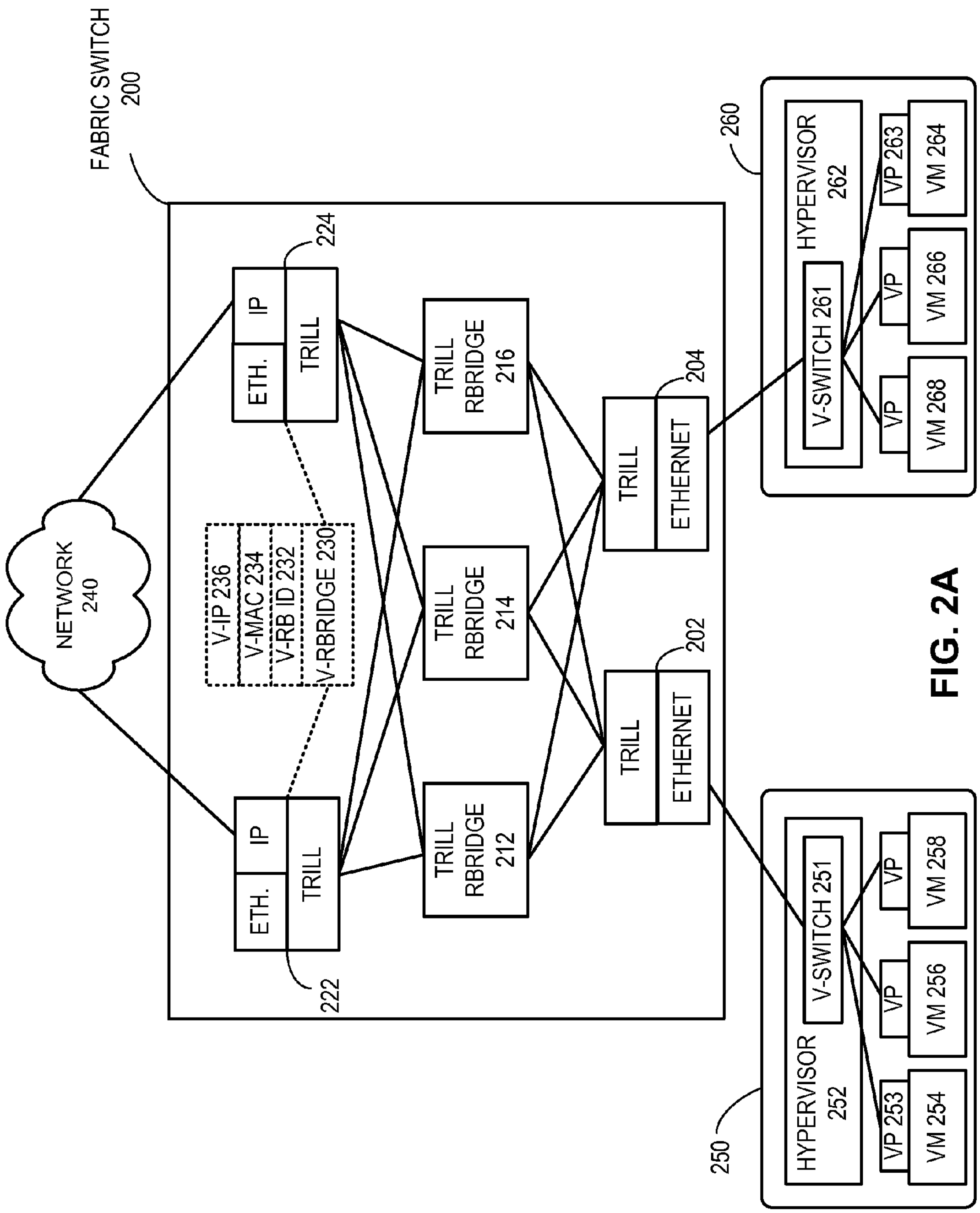

FABRIC SWITCH
200
NETWORK
240
ETH.
IP
TRILL
224
222
V-IP 236
V-MAC 234
V-RB ID 232
V-RBRIDGE 230
TRILL
RBRIDGE
216
TRILL
RBRIDGE
214
TRILL
RBRIDGE
212
TRILL
ETHERNET
204
202
260
HYPERVISOR
262
V-SWITCH 261
VP 263
VM 264
VP
VM 266
VP
VM 268
250
HYPERVISOR
252
V-SWITCH 251
VP 253
VM 254
VP
VM 256
VP
VM 258

FIG. 2A

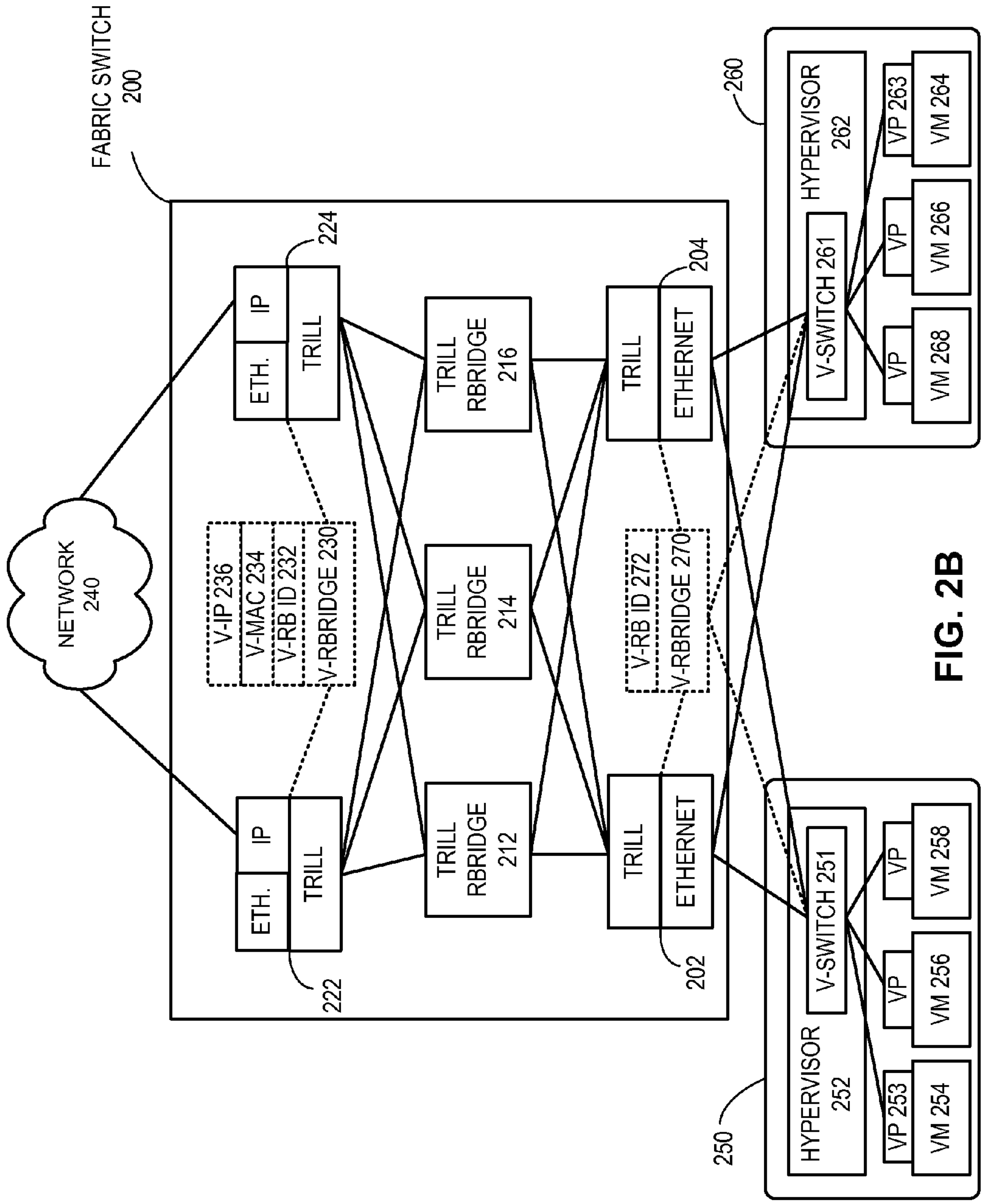

FABRIC SWITCH
200
NETWORK
240
ETH.
IP
TRILL
224
222
TRILL
RBRIDGE
216
TRILL
RBRIDGE
214
TRILL
RBRIDGE
212
V-IP 236
V-MAC 234
V-RB ID 232
V-RBRIDGE 230
TRILL
ETHERNET
204
202
V-RB ID 272
V-RBRIDGE 270
260
HYPERVISOR
262
V-SWITCH 261
VP 263
VM 264
VP
VM 266
VP
VM 268
250
HYPERVISOR
252
V-SWITCH 251
VP 253
VM 254
VP
VM 256
VP
VM 258

FIG. 2B

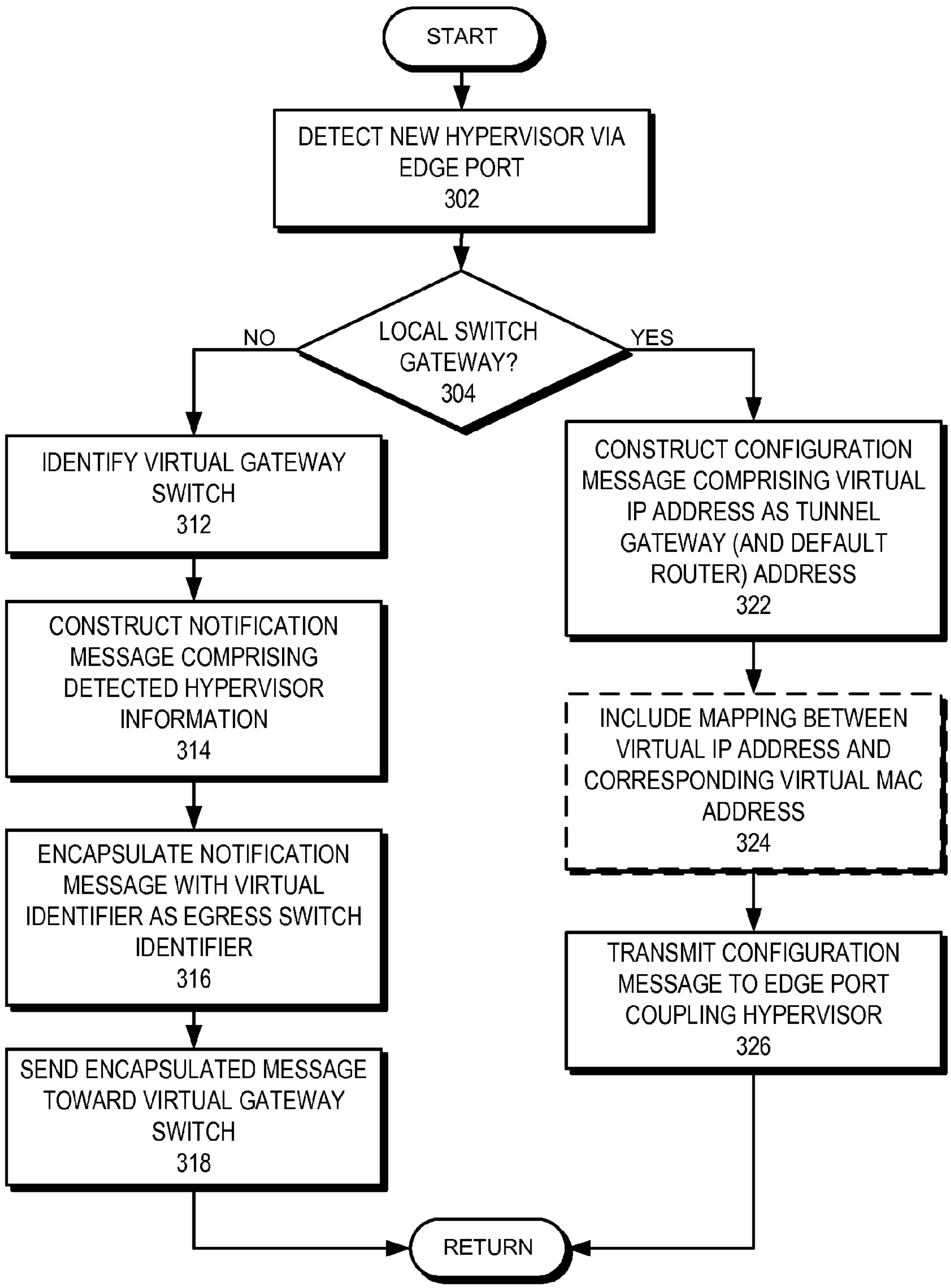

START
DETECT NEW HYPERVISOR VIA EDGE PORT 302
LOCAL SWITCH GATEWAY? 304
NO
YES
IDENTIFY VIRTUAL GATEWAY SWITCH 312
CONSTRUCT NOTIFICATION MESSAGE COMPRISING DETECTED HYPERVISOR INFORMATION 314
ENCAPSULATE NOTIFICATION MESSAGE WITH VIRTUAL IDENTIFIER AS EGRESS SWITCH IDENTIFIER 316
SEND ENCAPSULATED MESSAGE TOWARD VIRTUAL GATEWAY SWITCH 318
CONSTRUCT CONFIGURATION MESSAGE COMPRISING VIRTUAL IP ADDRESS AS TUNNEL GATEWAY (AND DEFAULT ROUTER) ADDRESS 322
INCLUDE MAPPING BETWEEN VIRTUAL IP ADDRESS AND CORRESPONDING VIRTUAL MAC ADDRESS 324
TRANSMIT CONFIGURATION MESSAGE TO EDGE PORT COUPLING HYPERVISOR 326
RETURN

FIG. 3A

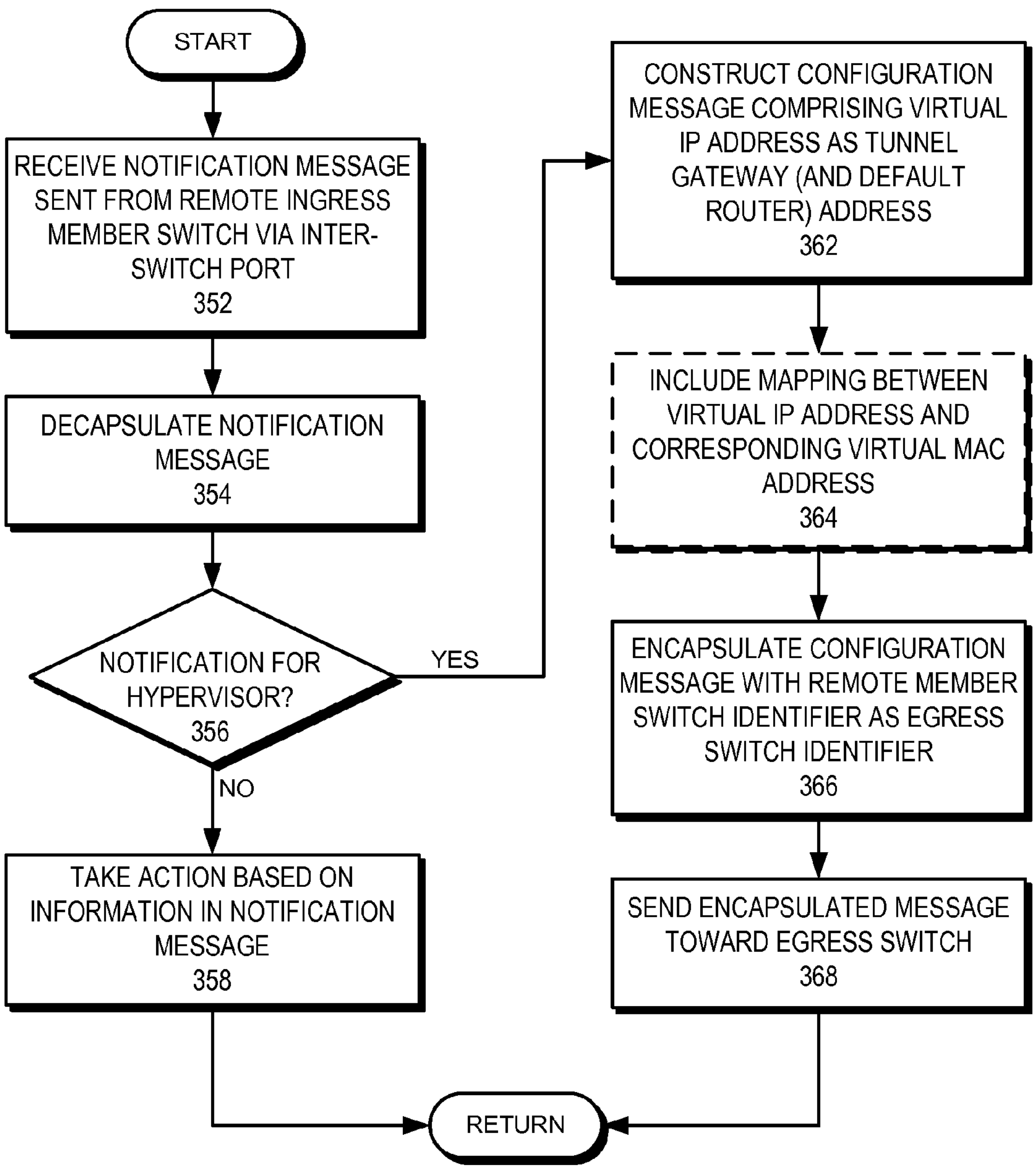

START
RECEIVE NOTIFICATION MESSAGE SENT FROM REMOTE INGRESS MEMBER SWITCH VIA INTER-SWITCH PORT
352
DECAPSULATE NOTIFICATION MESSAGE
354
NOTIFICATION FOR HYPERVISOR?
356
YES
NO
TAKE ACTION BASED ON INFORMATION IN NOTIFICATION MESSAGE
358
CONSTRUCT CONFIGURATION MESSAGE COMPRISING VIRTUAL IP ADDRESS AS TUNNEL GATEWAY (AND DEFAULT ROUTER) ADDRESS
362
INCLUDE MAPPING BETWEEN VIRTUAL IP ADDRESS AND CORRESPONDING VIRTUAL MAC ADDRESS
364
ENCAPSULATE CONFIGURATION MESSAGE WITH REMOTE MEMBER SWITCH IDENTIFIER AS EGRESS SWITCH IDENTIFIER
366
SEND ENCAPSULATED MESSAGE TOWARD EGRESS SWITCH
368
RETURN

FIG. 3B

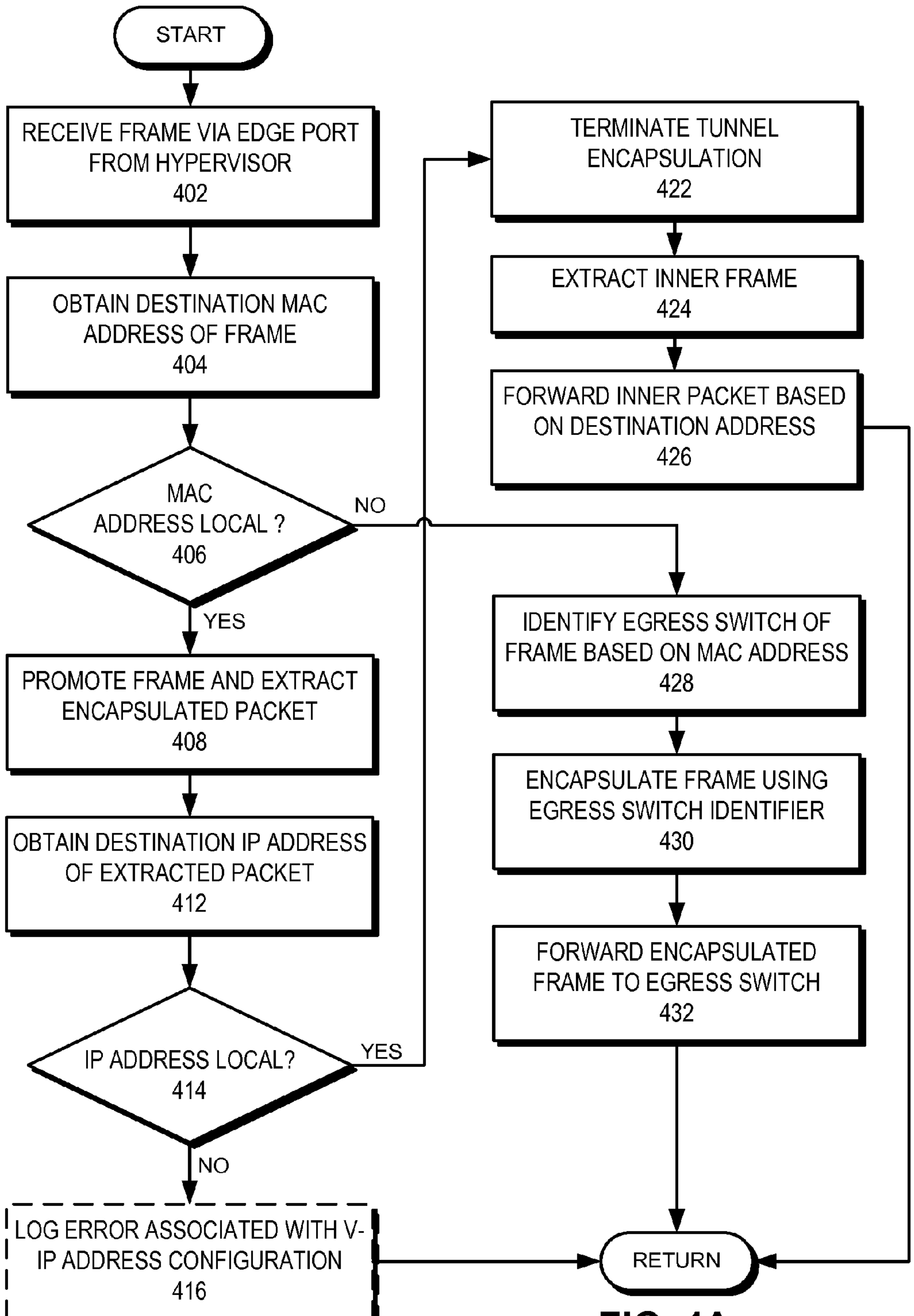
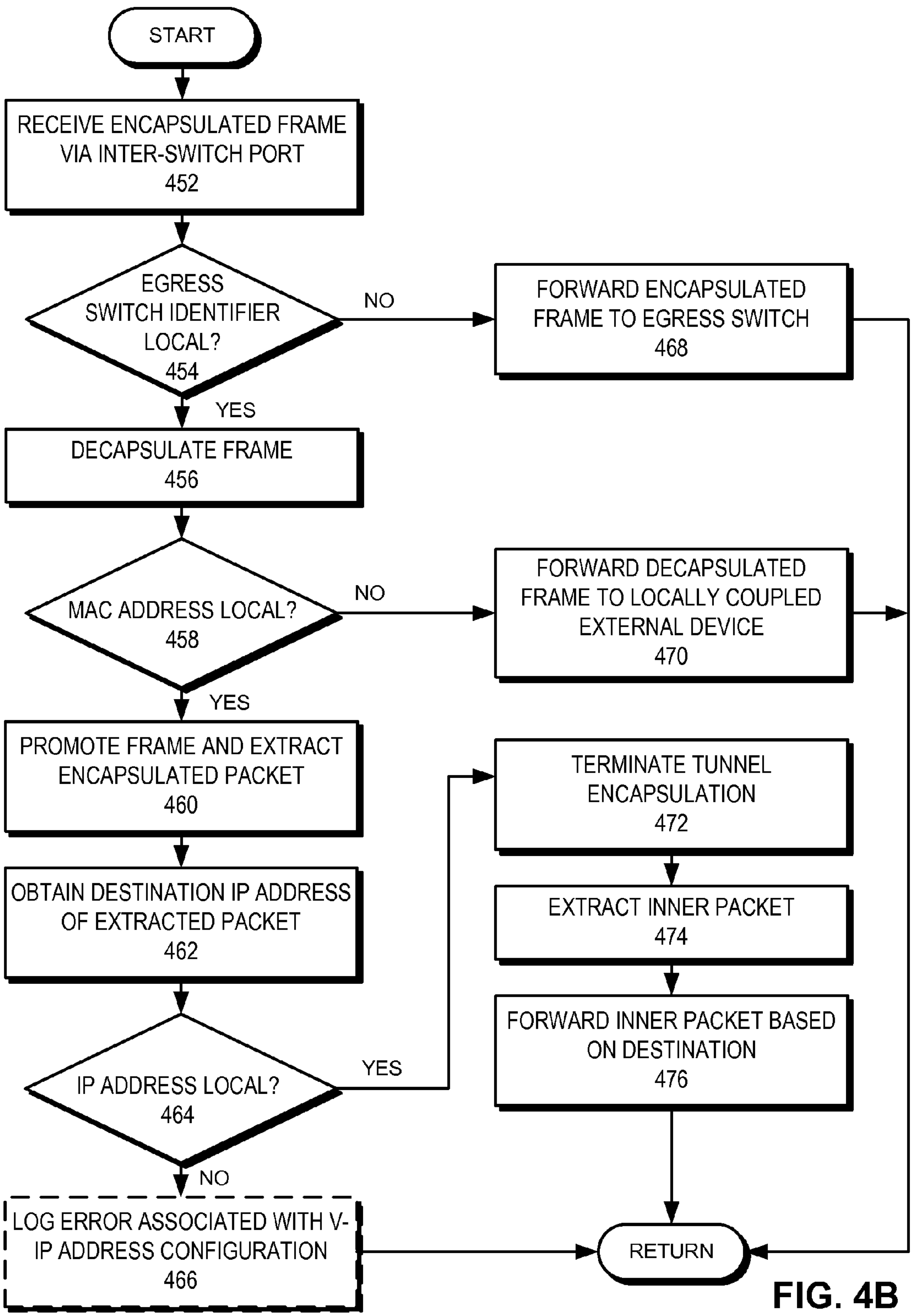

START
RECEIVE FRAME VIA EDGE PORT FROM HYPERVISOR
402
OBTAIN DESTINATION MAC ADDRESS OF FRAME
404
MAC ADDRESS LOCAL ?
406
NO
YES
PROMOTE FRAME AND EXTRACT ENCAPSULATED PACKET
408
OBTAIN DESTINATION IP ADDRESS OF EXTRACTED PACKET
412
IP ADDRESS LOCAL?
414
YES
NO
LOG ERROR ASSOCIATED WITH V-IP ADDRESS CONFIGURATION
416
TERMINATE TUNNEL ENCAPSULATION
422
EXTRACT INNER FRAME
424
FORWARD INNER PACKET BASED ON DESTINATION ADDRESS
426
IDENTIFY EGRESS SWITCH OF FRAME BASED ON MAC ADDRESS
428
ENCAPSULATE FRAME USING EGRESS SWITCH IDENTIFIER
430
FORWARD ENCAPSULATED FRAME TO EGRESS SWITCH
432
RETURN

FIG. 4A


START
RECEIVE ENCAPSULATED FRAME VIA INTER-SWITCH PORT
452
EGRESS SWITCH IDENTIFIER LOCAL?
454
NO
YES
FORWARD ENCAPSULATED FRAME TO EGRESS SWITCH
468
DECAPSULATE FRAME
456
MAC ADDRESS LOCAL?
458
NO
YES
FORWARD DECAPSULATED FRAME TO LOCALLY COUPLED EXTERNAL DEVICE
470
PROMOTE FRAME AND EXTRACT ENCAPSULATED PACKET
460
TERMINATE TUNNEL ENCAPSULATION
472
OBTAIN DESTINATION IP ADDRESS OF EXTRACTED PACKET
462
EXTRACT INNER PACKET
474
FORWARD INNER PACKET BASED ON DESTINATION
476
IP ADDRESS LOCAL?
464
YES
NO
LOG ERROR ASSOCIATED WITH V-IP ADDRESS CONFIGURATION
466
RETURN
FIG. 4B

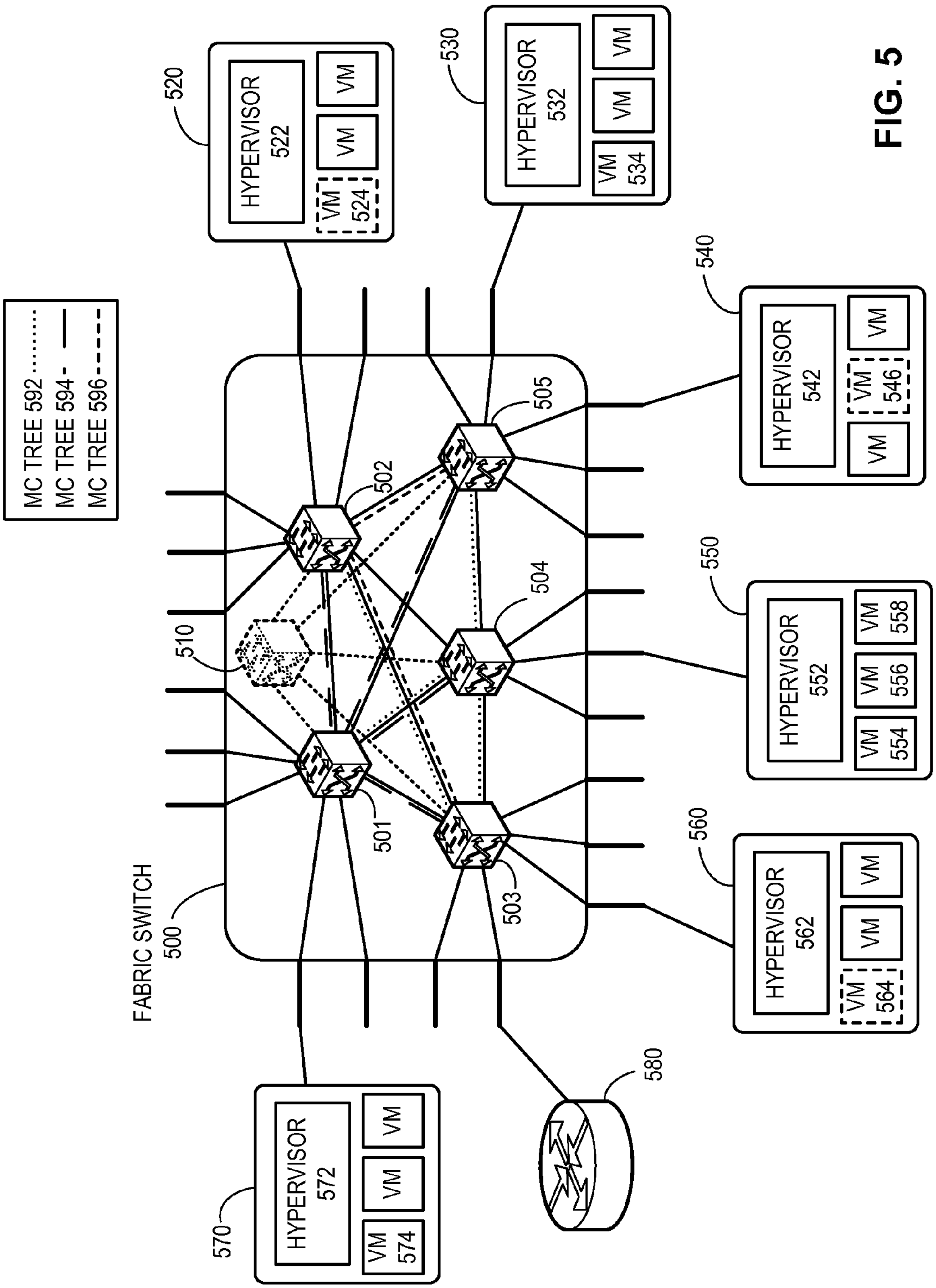

MC TREE 592
MC TREE 594
MC TREE 596
FABRIC SWITCH
500
501
502
503
504
505
510
520
HYPERVISOR
522
VM
524
530
HYPERVISOR
532
VM
534
540
HYPERVISOR
542
VM
546
550
HYPERVISOR
552
VM
554
556
558
560
HYPERVISOR
562
VM
564
570
HYPERVISOR
572
VM
574
580

FIG. 5

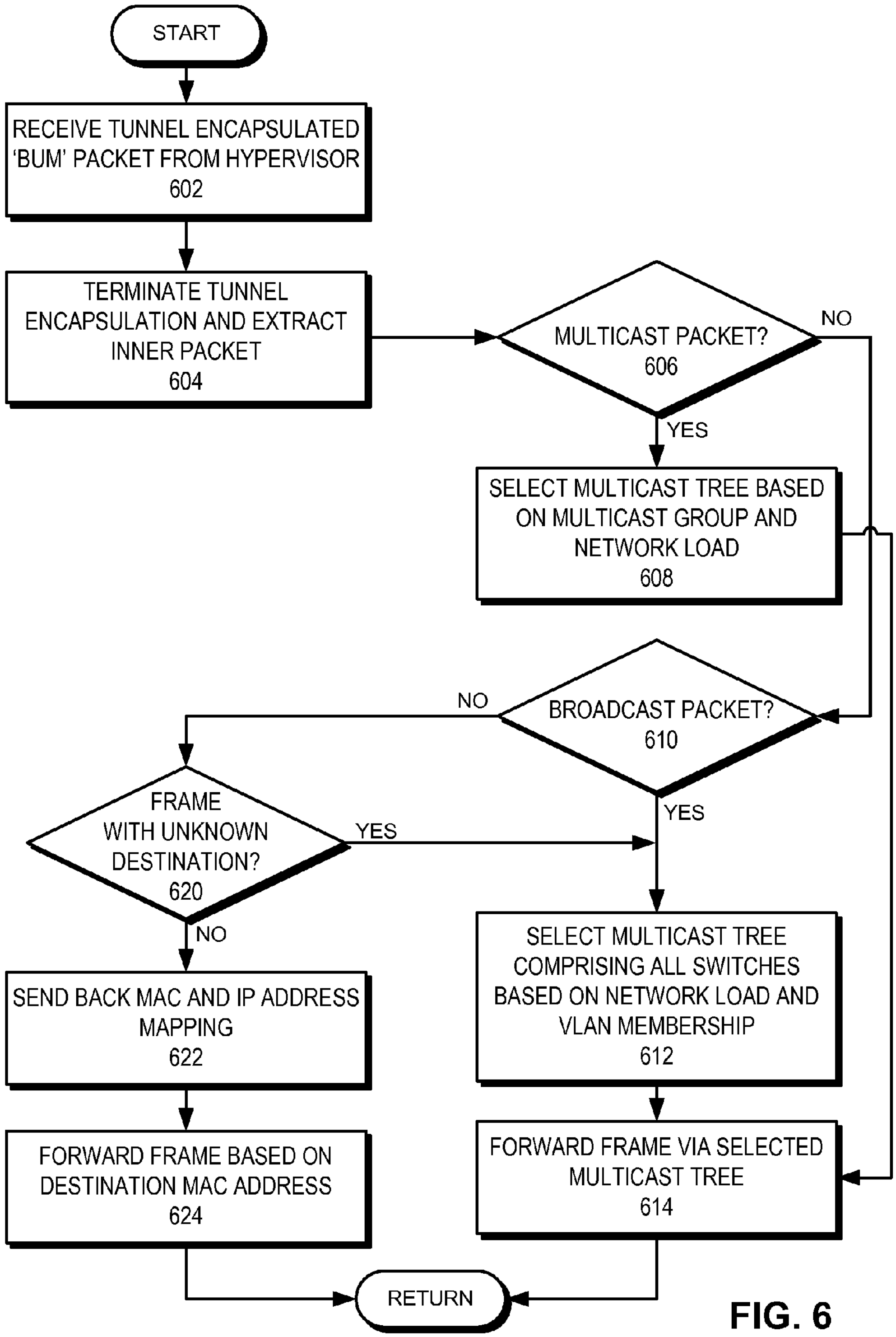

START
RECEIVE TUNNEL ENCAPSULATED 'BUM' PACKET FROM HYPERVISOR
602
TERMINATE TUNNEL ENCAPSULATION AND EXTRACT INNER PACKET
604
MULTICAST PACKET?
606
NO
YES
SELECT MULTICAST TREE BASED ON MULTICAST GROUP AND NETWORK LOAD
608
BROADCAST PACKET?
610
NO
YES
FRAME WITH UNKNOWN DESTINATION?
620
YES
NO
SEND BACK MAC AND IP ADDRESS MAPPING
622
FORWARD FRAME BASED ON DESTINATION MAC ADDRESS
624
SELECT MULTICAST TREE COMPRISING ALL SWITCHES BASED ON NETWORK LOAD AND VLAN MEMBERSHIP
612
FORWARD FRAME VIA SELECTED MULTICAST TREE
614
RETURN

FIG. 6

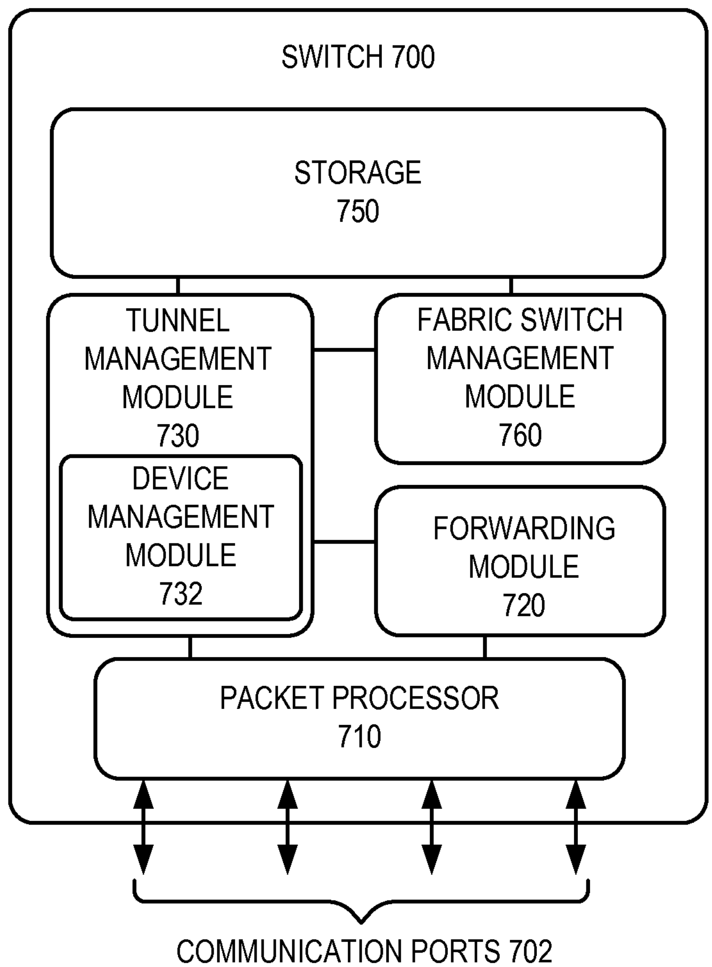

SWITCH 700
STORAGE 750
TUNNEL MANAGEMENT MODULE 730
DEVICE MANAGEMENT MODULE 732
FABRIC SWITCH MANAGEMENT MODULE 760
FORWARDING MODULE 720
PACKET PROCESSOR 710
COMMUNICATION PORTS 702

FIG. 7

OVERLAY TUNNEL IN A FABRIC SWITCH

RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/614,392, titled "Overlay L2/L3 Fabric Architecture," by inventor Phanidhar Koganti, filed 22 Mar. 2012, the disclosure of which is incorporated by reference herein.

The present disclosure is related to:

U.S. patent application Ser. No. 13/087,239, titled "Virtual Cluster Switching," by inventors Suresh Vobbilisetty and Dilip Chatwani, filed 14 Apr. 2011;

U.S. Patent Publication No. 2010/0246388, titled "Redundant Host Connection in a Routed Network," by inventors Somesh Gupta, Anoop Ghanwani, Phanidhar Koganti, and Shunjia Yu, filed 16 Mar. 2010;

U.S. patent application Ser. No. 13/312,903, titled "Layer-3 Support in TRILL Networks," by inventors Phanidhar Koganti, Anoop Ghanwani, Suresh Vobbilisetty, Rajiv Krishnamurthy, Nagarajan Venkatesan, and Shunjia Yu, filed 6 Dec. 2011; and

U.S. patent application Ser. No. 13/092,752, titled "Name Services for Virtual Cluster Switching," by inventors Suresh Vobbilisetty, Phanidhar Koganti, and Jesse B. Willeke, filed 22 Apr. 2011;

the disclosures of which are incorporated by reference herein.

BACKGROUND

1. Field

The present disclosure relates to network management. More specifically, the present disclosure relates to dynamic insertion of services in a fabric switch.

2. Related Art

The exponential growth of the Internet has made it a popular delivery medium for a variety of applications running on physical and virtual devices. Such applications have brought with them an increasing demand for bandwidth. As a result, equipment vendors race to build larger and faster switches with versatile capabilities, such as awareness of virtual machine migration, to move more traffic efficiently. However, the size of a switch cannot grow infinitely. It is limited by physical space, power consumption, and design complexity, to name a few factors. Furthermore, switches with higher capability are usually more complex and expensive. More importantly, because an overly large and complex system often does not provide economy of scale, simply increasing the size and capability of a switch may prove economically unviable due to the increased per-port cost.

A flexible way to improve the scalability of a switch system is to build a fabric switch. A fabric switch is a collection of individual member switches. These member switches form a single, logical switch that can have an arbitrary number of ports and an arbitrary topology. As demands grow, customers can adopt a "pay as you grow" approach to scale up the capacity of the fabric switch.

Meanwhile, layer-2 (e.g., Ethernet) switching technologies continue to evolve. More routing-like functionalities, which have traditionally been the characteristics of layer-3 (e.g., Internet Protocol or IP) networks, are migrating into layer-2. Notably, the recent development of the Transparent Interconnection of Lots of Links (TRILL) protocol allows Ethernet switches to function more like routing devices. TRILL overcomes the inherent inefficiency of the conventional spanning tree protocol, which forces layer-2 switches to be coupled in

a logical spanning-tree topology to avoid looping. TRILL allows routing bridges (RBridges) to be coupled in an arbitrary topology without the risk of looping by implementing routing functions in switches and including a hop count in the TRILL header.

As Internet traffic is becoming more diverse, virtual computing in a network is becoming progressively more important as a value proposition for network architects. In addition, the evolution of virtual computing has placed additional requirements on the network. For example, as the locations of virtual servers become more mobile and dynamic, it is often desirable that the network infrastructure can provide network overlay tunnels to assist the location changes of the virtual servers.

While a fabric switch brings many desirable features to a network, some issues remain unsolved in facilitating network overlay tunnels to support virtual machine migration.

SUMMARY

One embodiment of the present invention provides a switch. The switch includes a tunnel management module, a packet processor, and a forwarding module. The tunnel management module operates the switch as a tunnel gateway capable of terminating an overlay tunnel. During operation, the packet processor, which is coupled to the tunnel management module, identifies in a data packet a virtual Internet Protocol (IP) address associated with a virtual tunnel gateway. This virtual tunnel gateway is associated with the switch and the data packet is associated with the overlay tunnel. The forwarding module determines an output port for an inner packet in the data packet based on a destination address of the inner packet.

In a variation on this embodiment, a hypervisor controlling one or more virtual machines initiates the overlay tunnel by encapsulating the inner packet.

In a variation on this embodiment, the packet processor also identifies in the data packet a virtual media access control (MAC) address mapped to the virtual IP address.

In a variation on this embodiment, the switch also includes a device management module which operates in conjunction with the packet processor and generates for a hypervisor a configuration message comprising the virtual IP address as a tunnel gateway address.

In a further variation, the virtual IP address in the configuration message also corresponds to a default gateway router.

In a variation on this embodiment, the virtual IP address is further associated with a remote switch. This remote switch also operates as a tunnel gateway and is associated with the virtual tunnel gateway.

In a variation on this embodiment, the data packet is encapsulated based on the Transparent Interconnection of Lots of Links (TRILL) protocol. Under such a scenario, the packet processor also identifies a virtual routing bridge (RBridge) identifier, which is associated with the switch, in the data packet.

In a variation on this embodiment, the switch also includes a fabric switch management module which maintains a membership in a fabric switch. Such a fabric switch accommodates a plurality of switches and operates as a single logical switch.

In a further variation, the packet processor identifies the inner packet to be a broadcast, unknown unicast, or multicast packet. In response, the tunnel management module selects a multicast tree in the fabric switch to distribute the inner

packet based on one or more of: multicast group membership, virtual local area network (VLAN) membership, and network load.

In a variation on this embodiment, the tunnel management module operates in conjunction with the packet processor to learn a MAC address of a virtual machine via a tunnel initiated by a first hypervisor associated with the virtual machine.

In a further variation, the tunnel management module operates in conjunction with the packet processor to construct a message for a second hypervisor comprising an IP address of the first hypervisor in response to receiving a data frame with unknown destination from a virtual machine associated with the second hypervisor.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1**A illustrates an exemplary fabric switch with a virtual tunnel gateway, in accordance with an embodiment of the present invention.

FIG. **1**B illustrates a virtual tunnel gateway being associated with a respective member switch of a fabric switch in conjunction with the example in FIG. **1**A, in accordance with an embodiment of the present invention.

FIG. **2**A illustrates an exemplary configuration of a fabric switch with a virtual tunnel gateway, in accordance with an embodiment of the present invention.

FIG. **2**B illustrates exemplary multi-switch trunks coupling a plurality of member switches in a fabric switch, in accordance with an embodiment of the present invention.

FIG. **3**A presents a flowchart illustrating the process of a member switch in a fabric switch facilitating dynamic configuration of a hypervisor discovered via an edge port, in accordance with an embodiment of the present invention.

FIG. **3**B presents a flowchart illustrating the process of a member switch in a fabric switch facilitating dynamic configuration of a hypervisor discovered via an inter-switch port, in accordance with an embodiment of the present invention.

FIG. **4**A presents a flowchart illustrating the process of a member switch of a fabric switch forwarding a frame received via an edge port, in accordance with an embodiment of the present invention.

FIG. **4**B presents a flowchart illustrating the process of a member switch of a fabric switch forwarding a frame received via an inter-switch port, in accordance with an embodiment of the present invention.

FIG. **5** illustrates an exemplary processing of broadcast, unknown unicast, and multicast traffic in a fabric switch with a virtual tunnel gateway, in accordance with an embodiment of the present invention.

FIG. **6** presents a flowchart illustrating the process of a member tunnel gateway in a fabric switch processing broadcast, unknown unicast, and multicast traffic, in accordance with an embodiment of the present invention.

FIG. **7** illustrates an exemplary member switch associated with a virtual member tunnel gateway in a fabric switch, in accordance with an embodiment of the present invention.

In the figures, like reference numerals refer to the same figure elements.

DETAILED DESCRIPTION

The following description is presented to enable any person skilled in the art to make and use the invention, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not limited to the embodiments shown, but is to be accorded the widest scope consistent with the claims.

Overview

In embodiments of the present invention, the problem of facilitating overlay tunneling in a fabric switch is solved by operating one or more member switches of the fabric switch as tunnel gateways (which can be referred to as member tunnel gateways) virtualized as one virtual tunnel gateway. To achieve high utilization of network devices (e.g., servers and switches), a hypervisor often requires communication to physical and virtual devices which are external to its VLAN and cannot establish a tunnel with the hypervisor. For example, a default router of a network may support a different tunneling technology or may not support tunneling. A tunnel gateway allows the hypervisor to communicate beyond its VLAN boundaries without requiring any tunnel support from the desired destination. Whenever a hypervisor requires communication beyond its VLAN boundaries, the hypervisor initiates and establishes an overlay tunnel with the tunnel gateway, which in turn communicates with the desired destination.

Because a large number of hypervisors can be associated with a single network, the tunnel gateway of the network can become a bottleneck. To reduce the bottleneck, the network can include multiple tunnel gateways. Consequently, a respective hypervisor requires configurations to establish association with a tunnel gateway. For example, if the network has three tunnel gateways, a respective hypervisor is configured to associate with one of the three tunnel gateways. Furthermore, if the number of hypervisors increases, the existing tunnel gateways can again become a bottleneck. When an additional tunnel gateway is added to the network to reduce the bottleneck, the hypervisors require reconfigurations. Similarly, when a tunnel gateway fails, the hypervisors associated with the failed tunnel gateway need to be reassigned to the existing tunnel gateways. Such configurations and reconfigurations can be tedious, repetitious, and error-prone.

To solve this problem, the member switches, which are member tunnel gateways in a fabric switch, present the entire fabric switch as one single logical tunnel gateway to the local hypervisors. The member tunnel gateways are virtualized as a virtual member switch and a virtual member tunnel gateway. Other member switches, which are not member tunnel gateways, consider the virtual gateway switch as another member switch coupled to the member tunnel gateways. At the same time, the local hypervisors consider the virtual member tunnel gateway as a local tunnel gateway. The virtual member tunnel gateway is associated with a virtual Internet Protocol (IP) address and a virtual Media Access Control (MAC) address. A respective member tunnel gateway considers these virtual addresses as local addresses.

A respective hypervisor coupled to the fabric switch is dynamically configured to consider the virtual member tunnel gateway as the tunnel gateway for the hypervisor. This allows the whole fabric switch to act as a distributed tunnel gateway. As a result, the hypervisor can establish an overlay tunnel with any of the member tunnel gateways in the fabric switch associated with the virtual member tunnel gateway; and a member tunnel gateway can be dynamically added to or removed from the fabric switch without reconfiguring the local hypervisors. In this way, the fabric switch with a virtual tunnel gateway supports a large number of tunnels in a scalable way.

In some embodiments, the fabric switch is an Ethernet fabric switch. In an Ethernet fabric switch, any number of switches coupled in an arbitrary topology may logically operate as a single switch. Any new switch may join or leave the fabric switch in "plug-and-play" mode without any manual configuration. A fabric switch appears as a single logical switch to an external device. In some further embodiments, the fabric switch is a Transparent Interconnection of Lots of Links (TRILL) network and a respective member switch of the fabric switch is a TRILL routing bridge (RBridge).

Although the present disclosure is presented using examples based on the TRILL protocol, embodiments of the present invention are not limited to networks defined using TRILL, or a particular Open System Interconnection Reference Model (OSI reference model) layer. For example, embodiments of the present invention can also be applied to a multi-protocol label switching (MPLS) network. In this disclosure, the term "fabric switch" is used in a generic sense, and can refer to a network operating in any networking layer, sub-layer, or a combination of networking layers.

The term "external device" can refer to a device coupled to a fabric switch. An external device can be a host, a server, a conventional layer-2 switch, a layer-3 router, or any other type of device. Additionally, an external device can be coupled to other switches or hosts further away from a network. An external device can also be an aggregation point for a number of network devices to enter the network. The terms "device" and "machine" are used interchangeably.

The term "hypervisor" is used in a generic sense, and can refer to any virtual machine manager. Any software, firmware, or hardware that creates and runs virtual machines can be a "hypervisor." The term "virtual machine" also used in a generic sense and can refer to software implementation of a machine or device. Any virtual device which can execute a software program similar to a physical device can be a "virtual machine." A host external device on which a hypervisor runs one or more virtual machines can be referred to as a "host machine."

The term "tunnel" refers to a data communication where one or more networking protocols are encapsulated using another networking protocol. Although the present disclosure is presented using examples based on a layer-3 encapsulation of a layer-2 protocol, "tunnel" should not be interpreted as limiting embodiments of the present invention to layer-2 and layer-3 protocols. A "tunnel" can be established for any networking layer, sub-layer, or a combination of networking layers.

The term "frame" refers to a group of bits that can be transported together across a network. "Frame" should not be interpreted as limiting embodiments of the present invention to layer-2 networks. "Frame" can be replaced by other terminologies referring to a group of bits, such as "packet," "cell," or "datagram."

The term "switch" is used in a generic sense, and it can refer to any standalone or fabric switch operating in any network layer. "Switch" should not be interpreted as limiting embodiments of the present invention to layer-2 networks. Any device that can forward traffic to an external device or another switch can be referred to as a "switch." Examples of a "switch" include, but are not limited to, a layer-2 switch, a layer-3 router, a TRILL RBridge, or a fabric switch comprising a plurality of similar or heterogeneous smaller physical switches.

The term "RBridge" refers to routing bridges, which are bridges implementing the TRILL protocol as described in Internet Engineering Task Force (IETF) Request for Comments (RFC) "Routing Bridges (RBridges): Base Protocol Specification," available at http://tools.ietf.org/html/rfc6325, which is incorporated by reference herein. Embodiments of the present invention are not limited to application among RBridges. Other types of switches, routers, and forwarders can also be used.

The term "edge port" refers to a port in a fabric switch which exchanges data frames with an external device outside of the fabric switch. The term "inter-switch port" refers to a port which couples a member switch of a fabric switch with another member switch and is used for exchanging data frames between the member switches.

The term "switch identifier" refers to a group of bits that can be used to identify a switch. If the switch is an RBridge, the switch identifier can be an "RBridge identifier." The TRILL standard uses "RBridge ID" to denote a 48-bit Intermediate-System-to-Intermediate-System (IS-IS) ID assigned to an RBridge, and "RBridge nickname" to denote a 16-bit value that serves as an abbreviation for the "RBridge ID." In this disclosure, "switch identifier" is used as a generic term, is not limited to any bit format, and can refer to any format that can identify a switch. The term "RBridge identifier" is used in a generic sense, is not limited to any bit format, and can refer to "RBridge ID," "RBridge nickname," or any other format that can identify an RBridge.

The term "fabric switch" refers to a number of interconnected physical switches which form a single, scalable logical switch. In a fabric switch, any number of switches can be connected in an arbitrary topology, and the entire group of switches functions together as one single, logical switch. This feature makes it possible to use many smaller, inexpensive switches to construct a large fabric switch, which can be viewed as a single logical switch externally.

Network Architecture

FIG. **1**A illustrates an exemplary fabric switch with a virtual tunnel gateway, in accordance with an embodiment of the present invention. As illustrated in FIG. **1**A, a fabric switch **100** includes member switches **101**, **102**, **103**, **104**, and **105**. Switch **101** is coupled to service appliance **132** and a layer-3 router **134**; and switch **102** is coupled to layer-3 router **134** and a physical switch **136**. Appliance **132** can provide a service to fabric switch **100**, such as firewall protection, load balancing, and instruction detection. Member switches in fabric switch **100** send frames outside of fabric switch **100** via router **134**. Switch **136** can be coupled to other devices, such as a high-performance database. Member switches in fabric switch **100** use edge ports to communicate to external devices and inter-switch ports to communicate to other member switches. For example, switch **102** is coupled to external devices, such as router **134** and switch **136**, via edge ports and to switches **101**, **103**, **104**, and **105** via inter-switch ports.

Switches **101** and **102** also operate as tunnel gateways (i.e., member tunnel gateways **101** and **102**) in fabric switch **100**. Switches **101** and **102** are virtualized as a virtual gateway switch **150**. Switches **103**, **104**, and **105** consider virtual gateway switch **150** as another member switch reachable via switches **101** and **102**. Virtual gateway switch **150** is also virtualized as a virtual member tunnel gateway **150** to the hypervisors coupled to fabric switch **100**. Hence, the terms "member switch" and "member tunnel gateway" are used interchangeably for virtual gateway switch **150**, and associated member switches **101** and **102**. Virtual tunnel gateway **150** is associated with a virtual IP address and a virtual MAC address. Member tunnel gateways **101** and **102** are associated with these virtual addresses in conjunction with each other. Consequently, member tunnel gateways **101** and **102** consider these virtual addresses as local addresses. In some embodiments, fabric switch **100** is a TRILL network;

switches **101**, **102**, **103**, **104**, and **105** are RBridges; and data frames transmitted and received via inter-switch ports are encapsulated in TRILL headers. Under such a scenario, virtual member tunnel gateway **150** can be a virtual RBridge with a virtual RBridge identifier. Switch virtualization in a fabric switch and its associated operations, such as data frame forwarding, are specified in U.S. Patent Publication No. 2010/0246388, titled "Redundant Host Connection in a Routed Network," the disclosure of which is incorporated herein in its entirety.

Host machines **112** and **114** are coupled to switches **103** and **105**, respectively. During operation, switch **103** discovers the hypervisor of host machine **112**. Switch **103** then sends a configuration message to the hypervisor with the virtual IP address, and optionally, the virtual MAC address associated with virtual member tunnel gateway **150**. In some embodiments, switch **103** forwards the hypervisor information toward virtual gateway switch **150**. Switch **101** or **102** receives the information and sends the configuration message to the hypervisor via switch **103**. Upon receiving the configuration message, the hypervisor is dynamically configured with the virtual IP address as the tunnel gateway address. In the same way, the hypervisor in host machine **114** is also configured with the virtual IP address as the tunnel gateway address. This allows fabric switch **100** to act as a distributed tunnel gateway represented by virtual member tunnel gateway **150**.

Suppose that virtual machine **122** in host machine **112** initiates a data communication which crosses its VLAN boundary and sends an associated data frame toward router **134**. The hypervisor in host machine **112** initiates an overlay tunnel for the frame by encapsulating the frame in a layer-3 packet with the virtual IP address as the destination IP address. Examples of such a tunnel include, but are not limited to, Virtual Extensible Local Area Network (VXLAN), Generic Routing Encapsulation (GRE), and its variations, such as Network Virtualization using GRE (NVGRE) and openvSwitch GRE. The hypervisor in host machine **112** can further encapsulate the packet in an Ethernet frame with the virtual MAC address as the destination MAC address, and forwards the frame toward virtual member tunnel gateway **150**.

Upon receiving the frame, egress switch **103** identifies the destination MAC address to be associated with virtual gateway switch **150**. Switch **103** considers virtual gateway switch **150** to be another member switch and forwards the frame to switch **101**. Upon receiving the frame, switch **101** recognizes the virtual IP and MAC addresses to be local addresses, extracts the inner packet, and forwards the inner packet to router **134** based on the forwarding information of the inner packet. Similarly, if virtual machine **124** in host machine **114** sends a frame toward switch **136**, the hypervisor in host machine **114** tunnels the frame by encapsulating the frame in a layer-3 packet with the virtual IP address as the destination IP address. Switch **103** receives the frame, recognizes the virtual IP and MAC addresses to be local addresses, extracts the inner packet, and forwards the inner packet to switch **136** based on the forwarding information of the inner packet.

Suppose that virtual machine **122** requires migration from host machine **112** to a remote location via router **134**. The hypervisor of host machine **112** tunnels the data associated with the migration by encapsulating the data in an IP packet with the virtual IP address of virtual member tunnel gateway **150** as the destination address. On the other hand, if virtual machine **122** requires migration from host machine **112** to host machine **114**, the hypervisor of host machine **112** can simply send the associated data to the hypervisor of host machine **114**, as long as they are configured with the same VLAN. If virtual tunnel gateway **150** also operates a default router for the hypervisors in host machines **112** and **114**, the hypervisor of host machine **112** can tunnel the associated data directly to the hypervisor of host machine **114** via default router **150**. Member tunnel gateways **101** and **102** can age out the tunnels from the hypervisors of host machines **112** and **114** upon detecting inactivity from the tunnels. In some embodiments, member tunnel gateways **101** and **102** maintain an activity bit for a respective tunnel to indicate activity or inactivity over a period of time.

FIG. **1B** illustrates a virtual tunnel gateway being associated with a respective member switch of a fabric switch in conjunction with the example in FIG. **1A**, in accordance with an embodiment of the present invention. Because the entire fabric switch **100** appears as a single tunnel gateway represented by virtual member tunnel gateway **150**, another member tunnel gateway can be dynamically added to fabric switch **100**. In some embodiments, existing member switches can be configured as member tunnel gateways as well. In the example of FIG. **1B**, switches **103**, **104**, and **105** are also configured as member tunnel gateways. Switches **103**, **104**, and **105** become associated with virtual gateway switch **150**, and establish association with the corresponding virtual IP address and the virtual MAC address. The hypervisors of host machines **112** and **114** simply continue to tunnel frames by encapsulating the frames using the virtual IP address. Consequently, when the hypervisor in host machine **112** tunnels frames toward virtual member tunnel gateway **150**, egress switch **103** recognizes the virtual IP and MAC addresses and local addresses, extracts the inner frame, and forwards the frame to router **134** based on the forwarding information of the inner frame.

Network Configurations

FIG. **2A** illustrates an exemplary configuration of a fabric switch with a virtual tunnel gateway, in accordance with an embodiment of the present invention. In this example, a fabric switch **200** includes switches **212**, **214**, and **216**. Fabric switch **200** also includes switches **202**, **204**, **222** and **224**, each with a number of edge ports which can be coupled to external devices. For example, switches **202** and **204** are coupled with host machines **250** and **260** via Ethernet edge ports. Switches **222** and **224** are coupled to network **240**, which can be any local or wide area network, such as the Internet. Host machine **250** includes virtual machines **254**, **256**, and **258**, which are managed by hypervisor **252**. Host machine **260** includes virtual machines **264**, **266**, and **268**, which are managed by hypervisor **262**. Virtual machines in host machines **250** and **260** are logically coupled to virtual switches **251** and **261**, respectively, via their respective virtual ports. For example, virtual machines **254** and **264** are coupled to virtual switches **251** and **261**, respectively, via virtual ports **253** and **263**, respectively.

In some embodiments, switches in fabric switch **200** are TRILL RBridges and in communication with each other using TRILL protocol. These RBridges have TRILL-based inter-switch ports for connection with other TRILL RBridges in fabric switch **200**. Although the physical switches within fabric switch **200** are labeled as "TRILL RBridges," they are different from conventional TRILL RBridge in the sense that they are controlled by the Fibre Channel (FC) switch fabric control plane. In other words, the assignment of switch addresses, link discovery and maintenance, topology convergence, routing, and forwarding can be handled by the corresponding FC protocols. Particularly, each TRILL RBridge's switch ID or nickname is mapped from the corresponding FC switch domain ID, which can be automatically assigned when a switch joins fabric switch **200** (which is logically similar to an FC switch fabric).

Note that TRILL is only used as a transport between the switches within fabric switch **200**. This is because TRILL can readily accommodate native Ethernet frames. Also, the TRILL standards provide a ready-to-use forwarding mechanism that can be used in any routed network with arbitrary topology (although the actual routing in fabric switch **200** is done by the FC switch fabric protocols). Embodiments of the present invention should be not limited to using only TRILL as the transport. Other protocols (such as multi-protocol label switching (MPLS) or Internet Protocol (IP)), either public or proprietary, can also be used for the transport.

In the example in FIG. **2**, RBridges **222** and **224** are also member tunnel gateways. In some embodiments, a respective member tunnel gateway is capable of processing layer-3 (e.g., IP) packets to facilitate layer-3 overlay tunnels over layer-2 and TRILL network. RBridges **222** and **224** are virtualized as a virtual RBridge **230** (which corresponds to a virtual gateway switch) with virtual RBridge identifier **232**. RBridges **222** and **224** are associated with virtual RBridge identifier **232**. RBridges **202**, **204**, **212**, **214**, and **216** consider virtual RBridge **230** as another member switch reachable via RBridges **222** and **224**. Virtual RBridge **230** is presented to hypervisors **252** and **262** as virtual member tunnel gateway **230**. Hence, the terms "RBridge" and "member tunnel gateway" are used interchangeably for virtual RBridge **230**, and associated RBridges **222** and **224**. Virtual tunnel gateway **230** is associated with a virtual IP address **236** and a virtual MAC address **234**. Member tunnel gateways **222** and **224** are associated with virtual IP address **236** and virtual MAC address **234**. Consequently, member tunnel gateways **222** and **224** consider virtual IP address **236** and virtual MAC address **234** as local addresses.

During operation, RBridge **202** discovers hypervisor **252**. RBridge **202** then sends a configuration message to hypervisor **252** comprising virtual IP address **236**, and optionally, virtual MAC address **234**. If not provided, hypervisor **252** can obtain virtual MAC address **234** by sending an Address Resolution Protocol (ARP) query with virtual IP address **236**. RBridge **222** or **224** can resolve the ARP query and send a response comprising MAC address **234**. Managing a virtual IP address and a virtual MAC address in a fabric switch and its associated operations, such as ARP query resolution, are specified in U.S. patent application Ser. No. 13/312,903, titled "Layer-3 Support in TRILL Networks," the disclosure of which is incorporated herein in its entirety. In some embodiments, RBridge **202** forwards the hypervisor information toward virtual RBridge **230**, and, in response, RBridge **222** or **224** sends the configuration message to hypervisor **252** via switch **202**.

Upon receiving the configuration message, hypervisor **252** configures virtual IP address **236** as the tunnel gateway address, which can also be the default router IP address for hypervisor **252**. In some embodiments, RBridge **222** can use Dynamic Host Configuration Protocol (DHCP) for providing the configuration information. Similarly, upon receiving a configuration message from RBridge **204**, hypervisor **262** configures virtual IP address **236** as the tunnel gateway address for hypervisor **262**. Suppose that virtual machine **254** sends a frame toward network **240**. Hypervisor **252**, via virtual switch **251**, tunnels the frame by encapsulating the frame in a layer-3 packet with virtual IP address **236** as the destination IP address. Hypervisor **252** further encapsulates the packet in an Ethernet frame with virtual MAC address **234** as the destination MAC address, and forwards the frame to RBridge **202**. Upon receiving the frame, egress RBridge **202** identifies virtual MAC address **234** to be associated with virtual RBridge **230** reachable via RBridges **222** and **224**. RBridge **202** then encapsulates the frame in a TRILL packet with virtual RBridge identifier **232** as the egress RBridge identifier and forwards the frame toward virtual RBridge **230**.

The TRILL packet is received by one of intermediate RBridges **212** and **214**, and forwarded to RBridge **222** or **224** based on the TRILL routing in fabric switch **200**. Suppose that RBridge **222** receives the TRILL packet. RBridge **222** identifies virtual RBridge identifier **232** as the egress RBridge identifier and recognizes virtual RBridge identifier **232** as a local RBridge identifier. RBridge **222** removes the TRILL encapsulation and extracts the layer-2 frame. RBridge **222** identifies virtual MAC address **234** as the destination MAC address of the frame and recognizes virtual MAC address **234** to be a local MAC address. Because RBridge **222** has IP processing capability, RBridge **222** then promotes the packet in the frame to the upper layer (e.g., IP layer).

RBridge **222** identifies virtual IP address **232** as the destination IP address of the packet, recognizes virtual IP address **232** as a local IP address, and extracts the inner frame. RBridge **222** thus removes the tunneling encapsulation of hypervisor **252**. RBridge **222** then forwards the inner frame to network **240** based on the forwarding information of the inner frame. In this way, the entire fabric switch **200** operates as a tunnel gateway for hypervisor **252**.

When RBridge **222** removes the tunneling encapsulation, RBridge **222** learns the MAC address of virtual machine **254** from the inner frame. In some embodiments, RBridge **222** learns the MAC address of virtual machine **254** directly from the tunnel encapsulated packet. RBridge **222** can also learn other associated information, such as the MAC and IP addresses of hypervisor **252**, and outer and inner VLANs associated with the frame. In some embodiments, RBridge **222** shares the learned information with other member tunnel gateways in fabric switch **200**, such as RBridge **224**. RBridge **224** can consider the information received from RBridge **222** to be learned from a locally terminated tunnel.

In this way, RBridges **222** and **224** learn the MAC addresses (and the associated information) of virtual machines **256**, **258**, **264**, **266**, and **268** as well. In some embodiments, RBridges **222** and **224** share the learned MAC addresses with the rest of fabric switch **200**. RBridges **222** and **224** can also share the learned associated information with the rest of fabric switch **200** as well. Consequently, whenever any member switch of fabric switch **200** learns a MAC address, all other member switches learn the MAC address as well. In some embodiments, switches **202** and **204** use internal control messages to share the learned MAC addresses.

In some embodiments, all RBridges in fabric switch **200** operate as member tunnel gateways and are associated with virtual RBridge **230**. Under such a scenario, RBridge **202** removes tunneling encapsulation of hypervisor **252** and extracts the internal frame. RBridge **202** recognizes network **240** to be reachable via RBridges **222** and **224**. RBridge **202** then encapsulates the inner frame in a TRILL packet and forwards the TRILL-encapsulated inner frame toward one of RBridges **222** and **224**. If hypervisor **252** is sending multiple frames to network **240**, RBridge **202** can use equal cost multiple paths (ECMP). Hence, multi-pathing can be achieved when RBridges **202** and **204** choose to send TRILL-encapsulated data frames toward virtual RBridge **230** via RBridges **222** and **224**.

FIG. **2B** illustrates exemplary multi-switch trunks coupling a plurality of member switches in a fabric switch, in accordance with an embodiment of the present invention. As illustrated in FIG. 2B, RBridges **202** and **204** are configured to operate in a special "trunked" mode for host machines **250** and **260**, and hypervisors **252** and **262**. Hypervisors **252** and **262** view RBridges **202** and **204** as a common virtual RBridge **270**, with a corresponding virtual RBridge identifier **272**. Hypervisors **252** and **262** are considered to be logically coupled to virtual RBridge **270** via logical links represented by dotted lines. Virtual RBridge **270** is considered to be logically coupled to both RBridges **202** and **204**, optionally with zero-cost links (also represented by dotted lines).

While forwarding data frames from hypervisors **252** and **262**, RBridges **202** and **204** encapsulate the frame using the TRILL protocol and assign virtual RBridge identifier **272** as the ingress RBridge identifier. As a result, other RBridges in fabric switch **200** learn that hypervisors **252** and **262**, and their corresponding virtual machines are reachable via virtual RBridge **270**. In the following description, RBridges which participate in link aggregation are referred to as "partner RBridges." Since the two partner RBridges function as a single logical RBridge, the MAC address reachability learned by a respective RBridge is shared with the other partner RBridge. For example, during normal operation, virtual machine **254** may choose to send its outgoing data frames only via the link to RBridge **202**. As a result, only RBridge **202** would learn virtual machine **254**'s MAC address. This information is then shared by RBridge **202** with RBridge **204** via their respective inter-switch ports. In some embodiments, RBridges **202** and **204** can advertise their respective connectivity (optionally via zero-cost links) to virtual RBridge **270**. Hence, multi-pathing can be achieved when other RBridges choose to send data frames to virtual RBridge **270** (which is marked as the egress RBridge in the frames) via RBridges **202** and **204**.

Note that virtual RBridge **270** is distinct from virtual RBridge **230**. Virtual RBridge **230** represents the member tunnel gateways (i.e., the gateway switches) in fabric switch **200** as a single logical switch, and, in addition to virtual RBridge identifier **232**, is typically associated with virtual MAC address **234** and virtual IP address **236**. On the other hand, virtual RBridge **270** represents a multi-switch trunk as one logical connection via virtual RBridge **270**, and is associated with virtual RBridge identifier **272**. Fabric switch **200** can have a plurality of virtual RBridges associated with different multi-switch trunks.

Dynamic Configuration

In the example in FIG. **2**A, upon detecting hypervisor **252**, RBridge **222** dynamically provides configuration information, such as virtual IP address **236**, to hypervisor **252**. Hypervisor **252** then configures virtual IP address **236** as the tunnel gateway address, which can also be the default router IP address for hypervisor **252**. FIG. **3**A presents a flowchart illustrating the process of a member switch in a fabric switch facilitating dynamic configuration of a hypervisor discovered via an edge port, in accordance with an embodiment of the present invention. Upon detecting a new hypervisor via an edge port (operation **302**), the switch checks whether the local switch is a tunnel gateway (operation **304**). In some embodiments, the switch checks whether the local switch is associated with the virtual IP address to determine whether the local switch is a tunnel gateway.

If the local switch is not a tunnel gateway (operation **304**), the switch identifies the virtual gateway switch (operation **312**), which is also a virtual tunnel gateway. The switch constructs a notification message comprising detected hypervisor information (operation **314**) and encapsulates the notification message with a virtual identifier of the virtual gateway switch as the egress switch identifier (operation **316**). In some embodiments, the notification message is encapsulated in a TRILL packet and the virtual identifier is a virtual RBridge identifier. The switch then sends the encapsulated message toward the virtual gateway switch (operation **318**).

If the local switch is a tunnel gateway, the switch is aware of the virtual IP address and the virtual MAC address. The switch then constructs a configuration message comprising the virtual IP address as the tunnel gateway address for the hypervisor (operation **322**). This configuration message can be a layer-2 notification/control message. In some embodiments, the switch sends the configuration message using DHCP. The configuration message can also indicate the virtual IP address as the default router address for the hypervisor. The switch, operationally, can include a mapping between the virtual IP address and the corresponding virtual MAC address in the configuration message (operation **324**). If not included, upon receiving the configuration message, the hypervisor can obtain the virtual MAC address by sending an ARP query with the virtual IP address. The switch then transmits the configuration message to the edge port coupling the hypervisor (operation **326**).

FIG. **3**B presents a flowchart illustrating the process of a member switch in a fabric switch facilitating dynamic configuration of a hypervisor discovered via an inter-switch port, in accordance with an embodiment of the present invention. Upon receiving a notification message from a remote ingress member switch via an inter-switch port (operation **352**), the switch decapsulates the notification message (operation **354**). In some embodiments, the switch removes a TRILL and/or an FC header to decapsulate the notification message. The switch checks whether the notification message is for a new hypervisor (operation **356**). If not, the switch takes action based on the information in the notification message (operation **358**).

If the notification message is for a new hypervisor (operation **356**), the switch constructs a configuration message comprising the virtual IP address as the tunnel gateway address for the hypervisor (operation **362**). The configuration message can also indicate the virtual IP address as the default router address for the hypervisor. The switch, optionally, can include a mapping between the virtual IP address and the corresponding virtual MAC address in the configuration message (operation **364**). The switch encapsulates the configuration message with the remote member switch identifier as the egress switch identifier (operation **366**). In some embodiments, the notification message is encapsulated in a TRILL packet and the remote member switch identifier is an RBridge identifier. The switch then sends the encapsulated message toward the egress switch (operation **368**).

Frame Forwarding

FIG. **4**A presents a flowchart illustrating the process of a member switch of a fabric switch forwarding a frame received from a hypervisor via an edge port, in accordance with an embodiment of the present invention. The switch receives a data frame from the hypervisor via an edge port (operation **402**) and obtains the destination MAC address of the received frame (operation **404**). If the frame has a tunnel encapsulation, the destination MAC address is a virtual MAC address associated with the virtual tunnel gateway. The switch checks whether the MAC address is a local address (operation **406**). For example, if the switch is a member tunnel gateway, the virtual MAC address is a local address. If the destination MAC address is local, the switch promotes the frame to the upper layer (e.g., layer-3) and extracts the internal encapsulated packet (operation **408**) and obtains the IP address of the extracted packet (operation **412**).

The destination IP address of the extracted packet is a virtual IP address associated with the virtual tunnel gateway. The switch checks whether the destination IP address is a local address (operation **414**). For example, if the switch is a member tunnel gateway, the virtual IP address is a local address. If the IP address is local, the switch terminates the tunnel encapsulation (i.e., decapsulates the frame) (operation **422**). The switch extracts the inner frame (operation **424**) and forwards the inner frame based on the destination address of the inner frame (operation **426**), as described in conjunction with FIG. **2**A. If the IP address is not local (operation **414**), the switch is incorrectly configured. If the switch is configured with the virtual MAC address, the switch should also be configured with the corresponding virtual IP address. The switch can optionally log the error associated with the virtual IP address configuration (operation **416**).

If the MAC address is not associated with the switch (operation **406**), the frame can be a regular layer-2 frame without any tunnel encapsulation. The switch identifies the egress switch associated with the destination MAC address (operation **428**). Because a respective member switch in a fabric switch shares the learned MAC addresses with other member switches, the switch can be aware of the egress switch associated with the MAC address. The switch encapsulates the frame using an identifier of the egress switch (operation **430**). In some embodiments, the switch encapsulates the frame in a TRILL packet and assigns an RBridge identifier associated with the egress switch as the egress RBridge identifier. The switch then forwards the frame to the egress switch (operation **432**).

FIG. **4**B presents a flowchart illustrating the process of a member switch of a fabric switch forwarding a frame received via an inter-switch port, in accordance with an embodiment of the present invention. The switch receives an encapsulated frame via an inter-switch port (operation **452**) and checks whether the egress switch identifier is a local identifier (operation **454**). This local identifier can be a virtual switch identifier. If not, the switch forwards the frame toward the egress switch based on the egress switch identifier (operation **468**). If the identifier, which can be a virtual switch identifier, is local, the switch decapsulates the frame (operation **456**). In some embodiments, the frame encapsulation is based on the TRILL protocol and the egress switch identifier is a virtual RBridge identifier.

If the frame has a tunnel encapsulation, the destination MAC address of the decapsulated frame is a virtual MAC address associated with the virtual tunnel gateway. The switch checks whether the destination MAC address is a local address (operation **458**). For example, if the switch is a member tunnel gateway, the virtual MAC address is a local address. If the destination MAC address is not local, the frame is destined for a locally coupled external device, and the switch forwards the decapsulated frame to the locally coupled external device (operation **470**). If the MAC address is local, the switch promotes the frame to the upper layer and extracts the internal encapsulated packet (operation **460**), and obtains the IP address of the extracted packet (operation **462**).

The destination IP address of the extracted packet is a virtual IP address associated with the virtual tunnel gateway. The switch checks whether the IP address is a local address (operation **464**). For example, if the switch is a member tunnel gateway, the virtual IP address is a local address. If the IP address is local, the switch terminates the tunnel encapsulation (operation **472**). The switch extracts the inner packet (operation **474**) and forwards the inner packet based on the destination address of the inner packet (operation **476**), as described in conjunction with FIG. **2**A. If the destination IP address is not local, the switch is incorrectly configured. If the switch is configured with the virtual MAC address, the switch should also be configured with the virtual IP address. The switch can optionally log the error associated with the virtual IP address configuration (operation **466**).

Broadcast, Unknown Unicast, and Multicast Server

Typically broadcast, unknown unicast, or multicast traffic (which can be referred to as "BUM" traffic) is distributed to multiple recipients. For ease of deployment, hypervisors typically make multiple copies of the data frames belonging to such traffic and individually unicast the data frames. This often leads to inefficient usage of processing capability of the hypervisors, especially in a large scale deployment. To solve this problem, a fabric switch with a virtual tunnel gateway can facilitate efficient distribution of such traffic. FIG. **5** illustrates an exemplary processing of broadcast, unknown unicast, and multicast traffic in a fabric switch with a virtual tunnel gateway, in accordance with an embodiment of the present invention. As illustrated in FIG. **5**, a fabric switch **500** includes member switches **501**, **502**, **503**, **504**, and **505**. Member switches in fabric switch **500** use edge ports to communicate to external devices and inter-switch ports to communicate to other member switches

A respective member switch in fabric switch **500** operates as a member tunnel gateway. Switches **501**, **502**, **503**, **504**, and **505** are virtualized as a virtual member tunnel gateway **510** to hypervisors **522**, **532**, **542**, **552**, **562**, and **572** in host machines **520**, **530**, **540**, **550**, **560**, and **570**, respectively. Virtual tunnel gateway **510** is associated with a virtual IP address and a virtual MAC address. All member tunnel gateways consider these virtual addresses to be local addresses. In some embodiments, fabric switch **500** is a TRILL network; switches **501**, **502**, **503**, **504**, and **505** are RBridges; and data frames transmitted and received via inter-switch ports are encapsulated using the TRILL protocol. Under such a scenario, virtual member tunnel gateway **510** can be a virtual RBridge with a virtual RBridge identifier.

To facilitate multicast traffic distribution, fabric switch **500** maintains states for a respective multicast group associated with hypervisors **522**, **532**, **542**, **552**, **562**, and **572**. Note that such states are not proportional to the number of virtual machines coupled to the fabric, but are dependent on the number of multicast groups and VLANs associated with the virtual machines. A respective member tunnel gateway in fabric switch **500** is aware of the VLAN and multicast group association of a respective hypervisor. When a virtual machine sends a join or leave request for a multicast group, the corresponding hypervisor tunnels the request to the virtual IP address of virtual tunnel gateway **510**.

In some embodiments, a respective hypervisor implements a multicast proxy server (e.g., an Internet Group Management Protocol (IGMP) proxy server) and sends only the first join and last leave requests associated with a specific multicast group. For example, if virtual machines **554**, **556**, and **558** send join requests for a multicast group, hypervisor **552** sends only the first join request toward virtual member tunnel gateway **510**. On the other hand, if virtual machines **554** and **558** send leave requests for the multicast group, hypervisor **552** does not send out the leave requests because virtual machine **556** continues to receive traffic for the multicast group. However, when virtual machine **556** sends a leave request for the multicast group, hypervisor **552** recognizes it to be the last leave request and forwards the leave request toward virtual member tunnel gateway **510**.

During operation, virtual machines **524**, **546**, and **564** become members of a multicast group. When switch **503** receives a multicast frame from multicast router **580**, switch

503 forwards the frame via multicast tree 592. As a result, a respective switch in fabric switch receives the frame. Switches 502, 503, and 505 transmit the frame to corresponding hypervisors 522, 542, and 562, while switches 501 and 504 discard the frame. In some embodiments, switch 503 identifies virtual machines 524, 546, and 564 to be the members of the multicast group, and forwards the frame via multicast tree 596, which includes only switches 502, 503, and 505.

In some embodiments, fabric switch 500 operates as an ARP server. When virtual machine 534 sends an ARP request, instead of broadcasting (i.e., unicasting multiple copies), hypervisor 532 tunnels a single copy of the request toward virtual member tunnel gateway 510. Switch 505, which is also a member tunnel gateway, receives and decapsulates the request, as described in conjunction with FIGS. 2A and 2B. Switch 505 then distributes the request in fabric switch 500 via multicast tree 592. Similarly, when virtual machine 574 sends an ARP request, hypervisor 572 tunnels a single copy of the request toward virtual member tunnel gateway 510. Switch 501 receives the request and distributes the frame in fabric switch 500 via a different multicast tree 594. In this way, the member tunnel gateways in fabric switch 500 load balance across a plurality of multicast trees for broadcast, unknown unicast, or multicast traffic. Selection of multicast tree can further depend on VLAN memberships of the member switches.

FIG. 6 presents a flowchart illustrating the process of a member tunnel gateway in a fabric switch processing broadcast, unknown unicast, and multicast traffic, in accordance with an embodiment of the present invention. The member tunnel gateway receives a packet, which is part of a broadcast, unknown unicast, or multicast traffic flow, from a hypervisor (operation 602). This packet is encapsulated with the virtual MAC and IP addresses of a virtual member tunnel gateway, as described in conjunction with FIG. 5. The member tunnel gateway terminates the tunnel encapsulation and extracts the inner packet (operation 604), as described in conjunction with FIGS. 4A and 4B. The member tunnel gateway checks whether the packet is a multicast packet (operation 606). If so, the member tunnel gateway selects a multicast tree in the fabric switch based on the multicast group and the network load (operation 608).

If the packet is not a multicast packet, the member tunnel gateway checks whether the packet is a broadcast packet (operation 610). For example, an ARP request from a hypervisor is a layer-2 broadcast frame encapsulated in a layer-3 packet. If the packet is not a broadcast packet, the member tunnel gateway checks whether the packet is a frame of unknown destination (operation 620). If the packet is not a frame of unknown destination (i.e., the member tunnel gateway has already learned the destination MAC address), the member tunnel gateway sends back a mapping of the destination MAC address and the corresponding IP address (which can be a hypervisor IP address) (operation 622) and forwards the frame based on the destination MAC address (operation 624). For example, the MAC address can be associated with a remote member switch. The member tunnel gateway forwards the frame toward that remote member switch.

If the packet is a broadcast packet (operation 610) or the packet is a frame with unknown destination (operation 620), the member tunnel gateway selects a multicast tree comprising all switches in the fabric switch based on network load and VLAN configuration (operation 612). After selecting a multicast tree (operations 608 and 612), the member tunnel gateway forwards the frame via the selected multicast tree (operation 614). In some embodiments, for multicast traffic of a multicast group, the member tunnel gateway selects a multicast tree only with the member switches coupling virtual machines belonging to the multicast group (e.g., multicast tree 596 in the example in FIG. 5).

Exemplary Switch

FIG. 7 illustrates an exemplary member switch associated with a virtual member tunnel gateway in a fabric switch, in accordance with an embodiment of the present invention. In this example, a switch 700 includes a number of communication ports 702, a forwarding module 720, a tunnel management module 730, a packet processor 710 coupled to tunnel management module 730, and a storage 750. In some embodiments, switch 700 may maintain a membership in a fabric switch, wherein switch 700 also includes a fabric switch management module 760. Fabric switch management module 760 maintains a configuration database in storage 750 that maintains the configuration state of a respective switch within the fabric switch. Fabric switch management module 760 maintains the state of the fabric switch, which is used to join other switches. Under such a scenario, communication ports 702 can include inter-switch communication channels for communication within a fabric switch. This inter-switch communication channel can be implemented via a regular communication port and based on any open or proprietary format.

Tunnel management module 730 operates switch 700 as a tunnel gateway capable of terminating an overlay tunnel, as described in conjunction with FIG. 2A. Tunnel management module 730 also maintains an association between switch 700 and a virtual tunnel gateway. The virtual tunnel gateway is associated with a virtual IP address. If switch 700 is a member switch of a fabric switch, the virtual IP address can also be associated with another member switch of the fabric switch. This other member switch also operates as a tunnel gateway and is associated with the virtual tunnel gateway. In some embodiments, switch 700 is a TRILL RBridge. Under such a scenario, the virtual tunnel gateway is also associated with a virtual RBridge identifier.

In some embodiments, switch 700 also includes a device management module 732, which operates in conjunction with the packet processor. Upon detecting a new hypervisor, device management module 732 generates a configuration message comprising the virtual IP address as a tunnel gateway address for the hypervisor, as described in conjunction with FIGS. 3A and 3B. In some embodiments, the virtual IP address in the configuration message also corresponds to a default gateway router. During operation, the hypervisor initiates an overlay tunnel with switch 700 by encapsulating inner data packets in another layer-3 data packet.

Upon receiving the tunnel encapsulated data packet from the hypervisor, packet processor 710 identifies in the data packet the virtual IP address associated with the virtual tunnel gateway and extracts the inner packet from the data packet. In some embodiments, the packet is TRILL encapsulated and is received via one of the communication ports 702 capable of receiving TRILL packets. Packet processor 710 identifies the virtual RBridge identifier in the TRILL header, as described in conjunction with FIG. 2A. Forwarding module 720 then determines an output port from one of the communication ports 702 for the inner packet based on the destination address of the inner packet. To facilitate layer-2 switching, the encapsulated data packet can include a virtual MAC address mapped to the virtual IP address. Packet processor 710 can identify this virtual MAC address in the data packet as well.

Note that the above-mentioned modules can be implemented in hardware as well as in software. In one embodiment, these modules can be embodied in computer-executable instructions stored in a memory which is coupled to one or more processors in switch **700**. When executed, these instructions cause the processor(s) to perform the aforementioned functions.

In summary, embodiments of the present invention provide a switch and a method for facilitating overlay tunneling in a fabric switch. In one embodiment, the switch includes a tunnel management module, a packet processor, and a forwarding module. The tunnel management module operates the switch as a tunnel gateway capable of terminating an overlay tunnel. During operation, the packet processor, which is coupled to the tunnel management module, identifies in a data packet a virtual IP address associated with a virtual tunnel gateway. This virtual tunnel gateway is associated with the switch and the data packet is associated with the overlay tunnel. The forwarding module determines an output port for an inner packet in the data packet based on a destination address of the inner packet.

The methods and processes described herein can be embodied as code and/or data, which can be stored in a computer-readable non-transitory storage medium. When a computer system reads and executes the code and/or data stored on the computer-readable non-transitory storage medium, the computer system performs the methods and processes embodied as data structures and code and stored within the medium.

The methods and processes described herein can be executed by and/or included in hardware modules or apparatus. These modules or apparatus may include, but are not limited to, an application-specific integrated circuit (ASIC) chip, a field-programmable gate array (FPGA), a dedicated or shared processor that executes a particular software module or a piece of code at a particular time, and/or other programmable-logic devices now known or later developed. When the hardware modules or apparatus are activated, they perform the methods and processes included within them.

The foregoing descriptions of embodiments of the present invention have been presented only for purposes of illustration and description. They are not intended to be exhaustive or to limit this disclosure. Accordingly, many modifications and variations will be apparent to practitioners skilled in the art. The scope of the present invention is defined by the appended claims.

What is claimed is:

1. A switch, comprising:
- a tunnel management module configurable to:
  - operate the switch as a tunnel gateway capable of terminating an overlay tunnel;
  - learn a MAC address of a virtual machine via a tunnel initiated by a first hypervisor associated with the virtual machine; and
  - construct a message for a second hypervisor comprising an Internet Protocol (IP) address of the first hypervisor in response to receiving a data frame with unknown destination from a virtual machine associated with the second hypervisor; and
- a packet processor configurable to identify in a data packet a virtual IP address associated with a virtual tunnel gateway, wherein the virtual tunnel gateway is associated with the switch; and
- a forwarding module configurable to determine an output port for an inner packet in the data packet based on a destination address of the inner packet.

2. The switch of claim **1**, wherein the tunnel management module is further configurable to identify a hypervisor controlling a virtual machine, wherein the virtual machine initiates the overlay tunnel by encapsulating the inner packet using the virtual IP address.

3. The switch of claim **1**, wherein the packet processor is further configurable to identify in the data packet a virtual media access control (MAC) address corresponding to the virtual IP address.

4. The switch of claim **1**, further comprising a device management module configurable to generate a configuration message comprising the virtual IP address as a tunnel gateway address in response to detecting a hypervisor.

5. The switch of claim **4**, wherein the virtual IP address in the configuration message corresponds to a default gateway router.

6. The switch of claim **1**, wherein the virtual IP address is further associated with a remote switch, wherein the remote switch operates as a tunnel gateway and is associated with the virtual tunnel gateway.

7. The switch of claim **1**,
- wherein the packet processor is further configurable to:
  - encapsulate the data packet in an encapsulation packet; and
  - including a virtual switch identifier as an ingress switch identifier of the encapsulation packet; and
- wherein the switch identifier is associated with the switch.

8. The switch of claim **1**, further comprising a switch management module configurable to maintain a membership in a network of interconnected switches.

9. The switch of claim **8**, wherein the packet processor is further configurable to identify the inner packet to be a broadcast, unknown unicast, or multicast packet; and
- wherein the tunnel management module is further configurable to select a multicast tree in the network to distribute the inner packet based on one or more of: multicast group membership, virtual local area network (VLAN) membership, and network load.

10. The switch of claim **8**, wherein the virtual tunnel gateway appears as a member switch of the network.

11. The switch of claim **1**, wherein the packet processor is further configurable to construct an Address Resolution Protocol (ARP) response message comprising a virtual MAC address associated with the switch in response to an ARP query message for the virtual IP address.

12. A computer-executable method, comprising:
- operating a switch as a tunnel gateway capable of terminating an overlay tunnel;
- learning a MAC address of a virtual machine via a tunnel initiated by a first hypervisor associated with the virtual machine;
- constructing a message for a second hypervisor comprising an Internet Protocol (IP) address of the first hypervisor in response to receiving a data frame with unknown destination from a virtual machine associated with the second hypervisor; and
- identifying in a data packet a virtual IP address associated with a virtual tunnel gateway, wherein the virtual tunnel gateway is associated with the switch; and
- determining an output port for an inner packet in the data packet based on a destination address of the inner packet.

13. The method of claim **12**, further comprising identifying a hypervisor controlling a virtual machine, wherein the virtual machine initiates the overlay tunnel by encapsulating the inner packet using the virtual IP address.

14. The method of claim **12**, further comprising identifying in the data packet a virtual media access control (MAC) address corresponding to the virtual IP address.

15. The method of claim 12, further comprising generating a configuration message comprising the virtual IP address as a tunnel gateway address in response to detecting a hypervisor.

16. The method of claim 15, wherein the virtual IP address in the configuration message corresponds to a default gateway router.

17. The method of claim 12, wherein the virtual IP address is further associated with a remote switch, wherein the remote switch operates as a tunnel gateway and is associated with the virtual tunnel gateway.

18. The method of claim 12, further comprising:

encapsulating the data packet in an encapsulation packet; and

identifying a virtual switch identifier as an ingress switch identifier of the encapsulation packet; and

wherein the virtual switch identifier is associated with the switch.

19. The method of claim 12, further comprising maintaining a membership in a network of interconnected switches.

20. The method of claim 19, further comprising:

identifying the inner packet to be a broadcast, unknown unicast, or multicast packet; and

selecting a multicast tree in the network to distribute the inner packet based on one or more of: multicast group membership, virtual local area network (VLAN) membership, and network load.

21. The method of claim 19, wherein the virtual tunnel gateway appears as a member switch of the network.

22. The method of claim 12, further comprising constructing an Address Resolution Protocol (ARP) response message comprising a virtual MAC address associated with the switch in response to an ARP query message for the virtual IP address.

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